MSFC CLASP Instrument Capability & Changes Needed for PRIMROSE

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Why the chromosphere?
Why now?

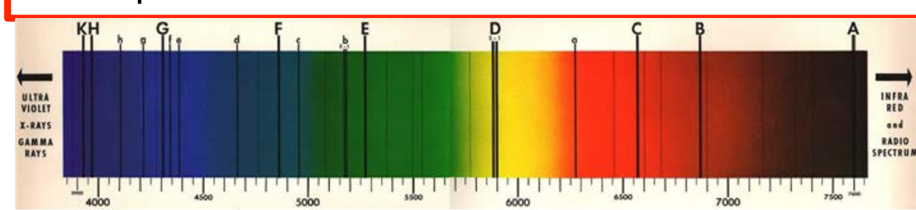
SHP2. Determine how the Sun's magnetism creates its dynamic atmosphere.

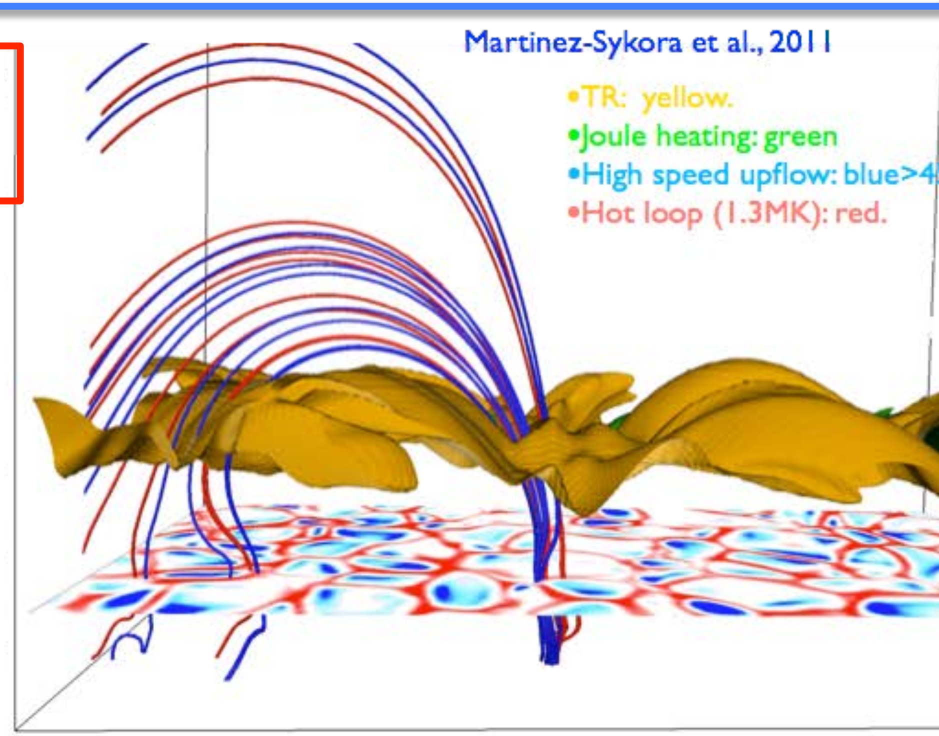
a. Determine whether chromospheric dynamics is the origin of heat and mass fluxes into the corona and solar wind.
b. Determine how magnetic free energy is transmitted from the photosphere to the corona.
c. Discover how the thermal structure of the closed-field corona is determined.
d. Discover the origin of the solar wind's dynamics and structure.

Solar and Space Physics: A Science for a Technological Society, 2013

Advances in theoretical modeling of the chromosphere and transition region allow for prediction and interpretation of the results.

Magnetically sensitive spectral lines formed in chromosphere are not in the visible wavelength range, so measurements have to go above atmosphere.





Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)

Science Goal 1: Detect scattering polarization in the wings of Lyman-alpha.

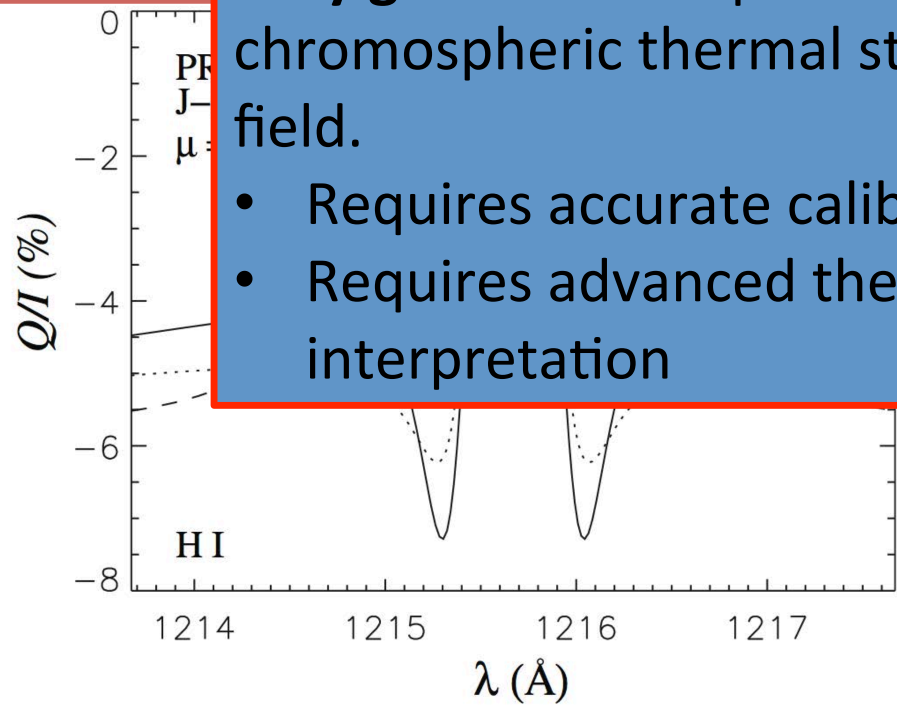
- Sensitive to the thermal structure of the chromosphere.
- Not sensitive to magnetic field
- Magnitu

Science Goal 2: Detect polarization in the line core.

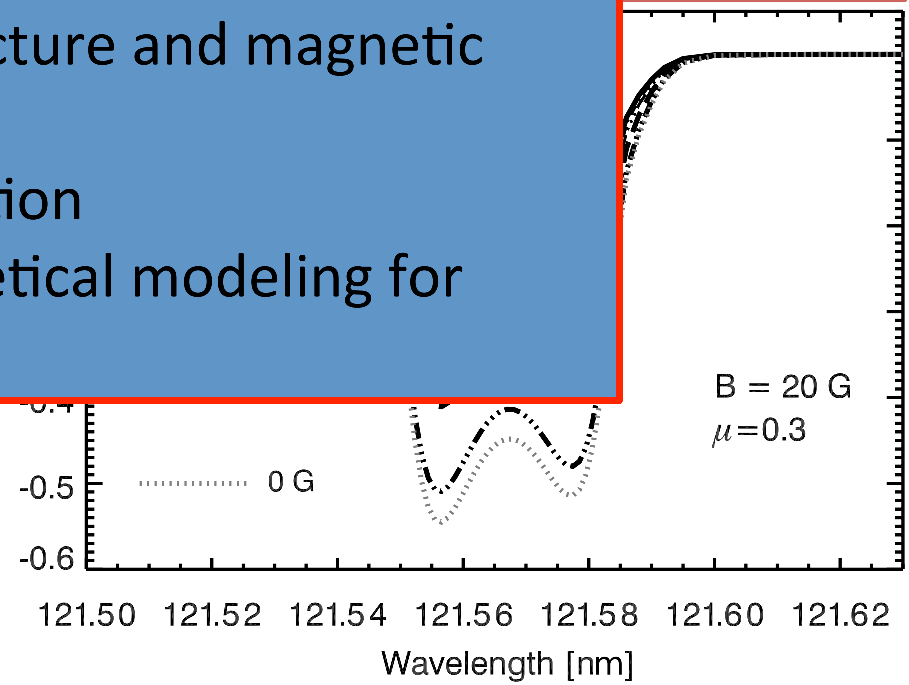
- Modified by the magnetic field through Hanle effect
- Magnitude of the polarization is ~ 0.1%
- Accuracy required technological advances in
- ector systems

Holy grail: Use the polarization to infer the chromospheric thermal structure and magnetic field.

- Requires accurate calibration
- Requires advanced theoretical modeling for interpretation

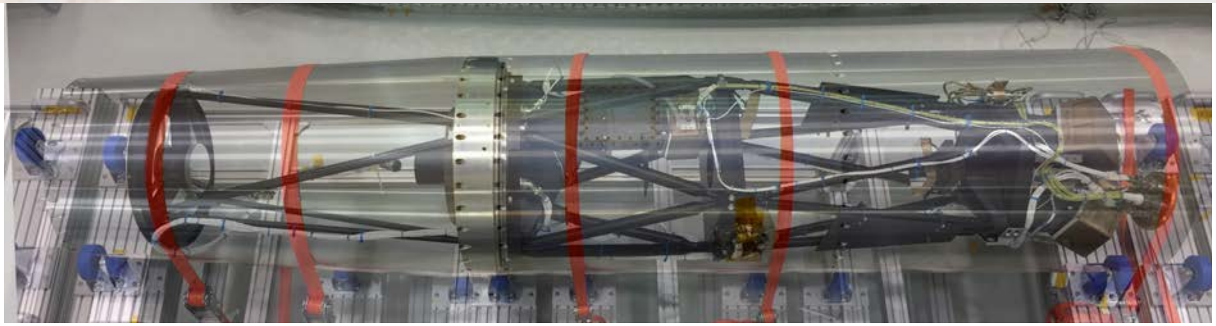


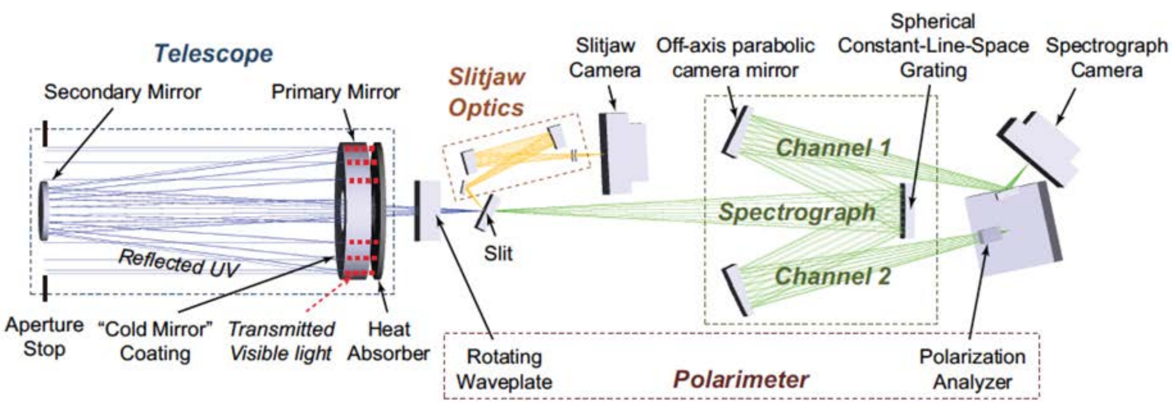
Belluzzi et al. 2012



Trujillo Bueno et al. 2011

Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)





CLASP is a dual channel spectropolarimeter to measure the polarization of Lyman-alpha.

CLASP was designed and built through an international partnership. Scientists from 11 organizations and 6 countries form the CLASP team. Primary teams and responsibilities are listed below.

MSFC/USA (PI: A. Winebarger) – Cameras, avionics, project management, coordination w/ NASA launch team

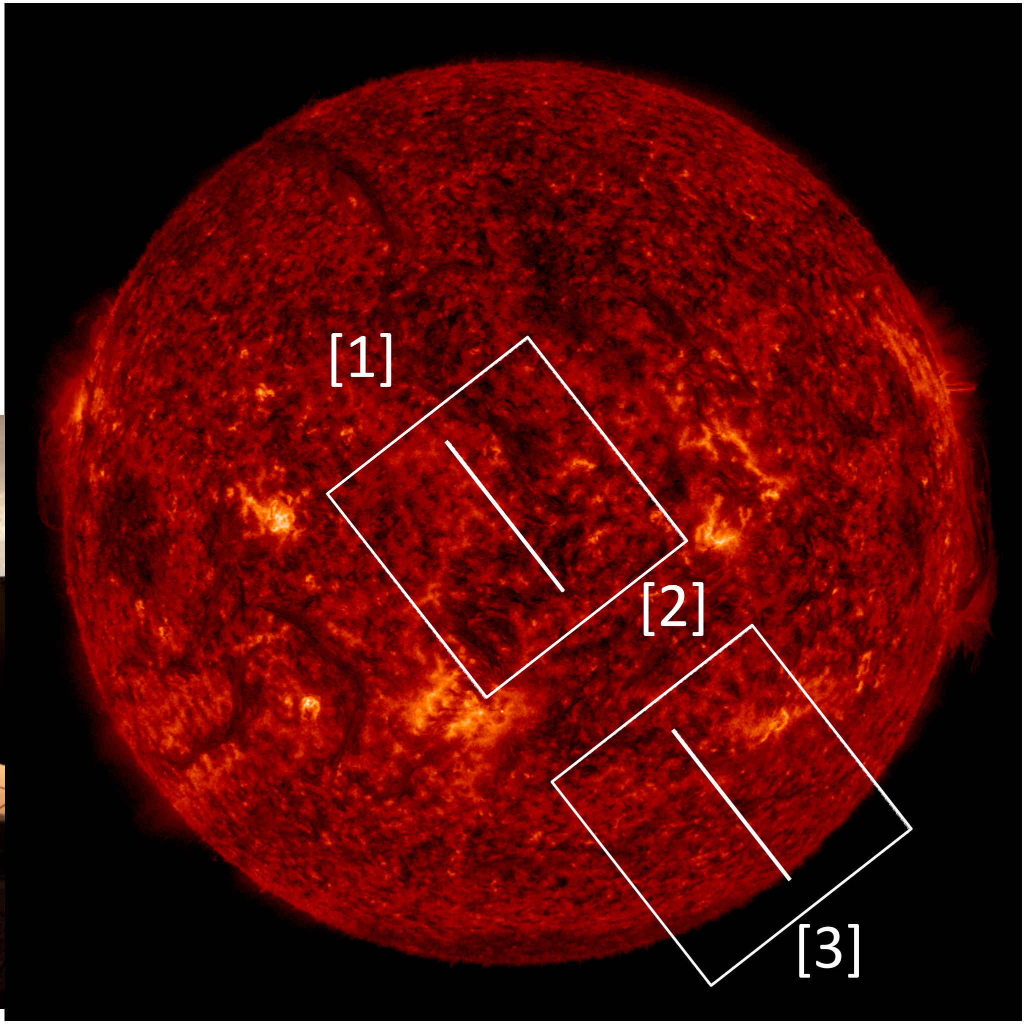
NAOJ & JAXA/Japan (Co-PI: R. Kano) – Optics & opto-mechanics, instrument structure

IAS/France (Co-PI: F. Auchère) – Diffraction Grating

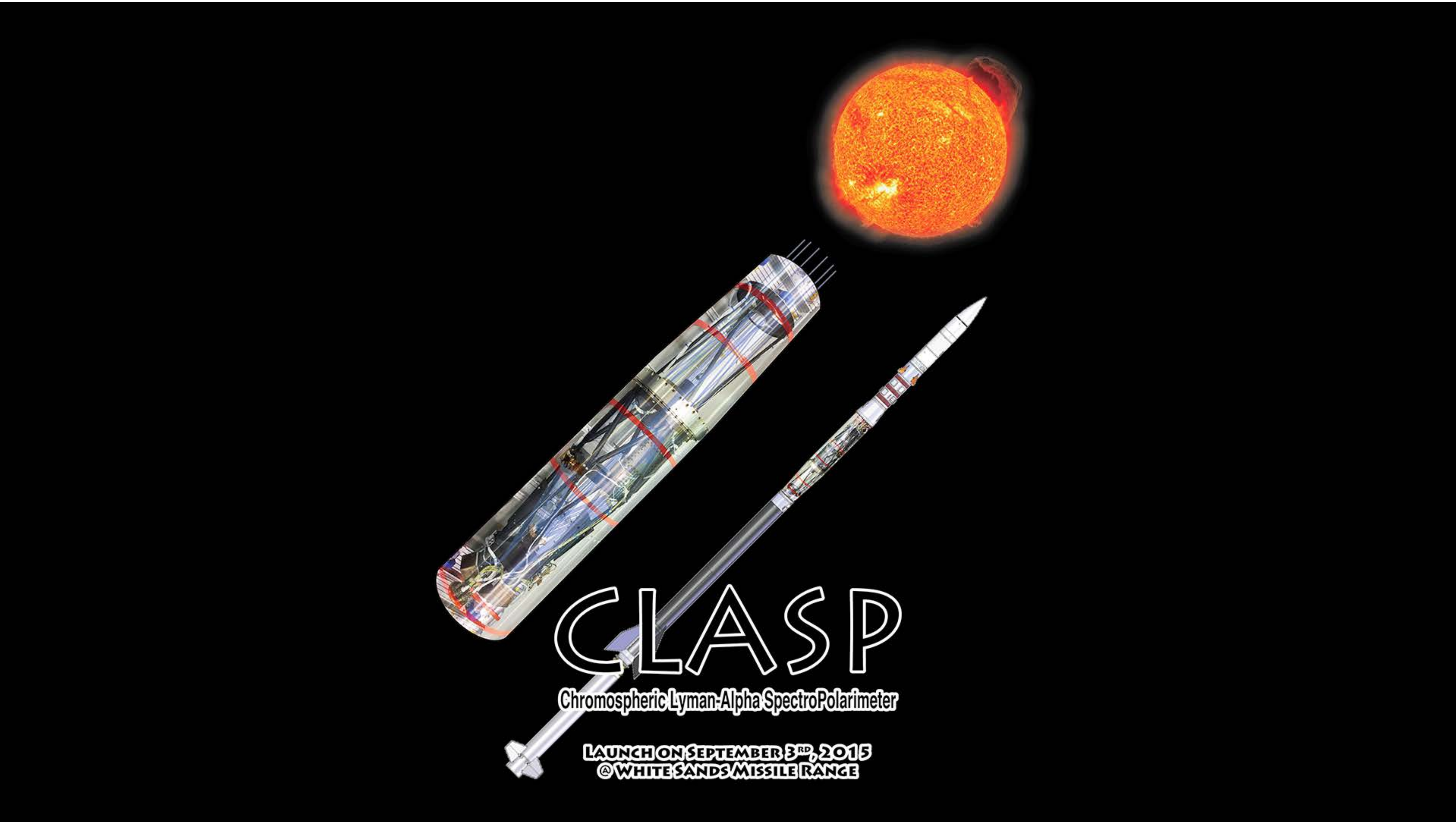
IAC/Spain (Co-PI: J. Trujillo Bueno) – Theoretical predictions and modeling of the Hanle effect

Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)

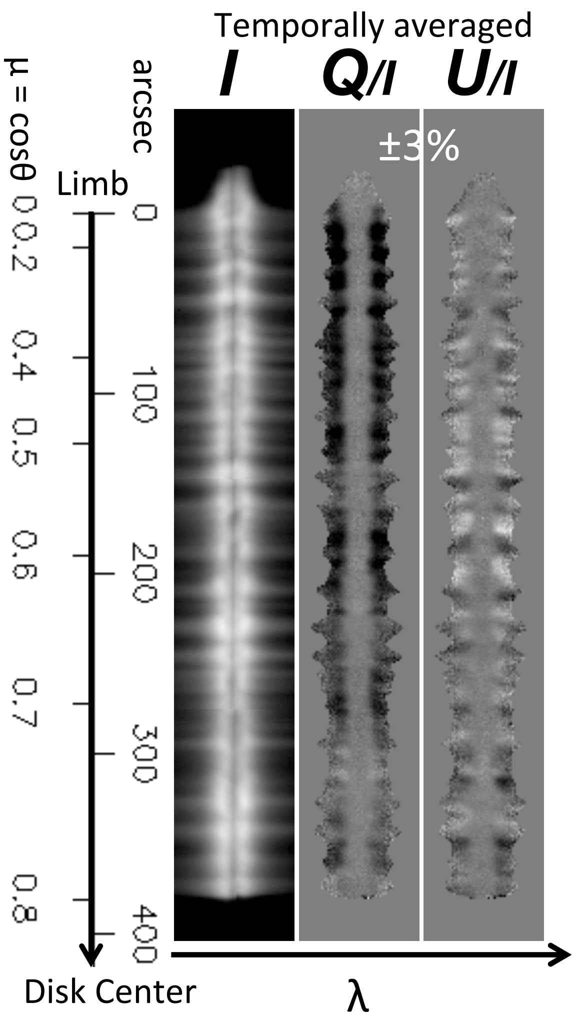
CLASP was launched on September 3, 2015 from White Sand Missile Range



Chromospheric Lyman-Alpha Spectropolarimeter (CLASP)

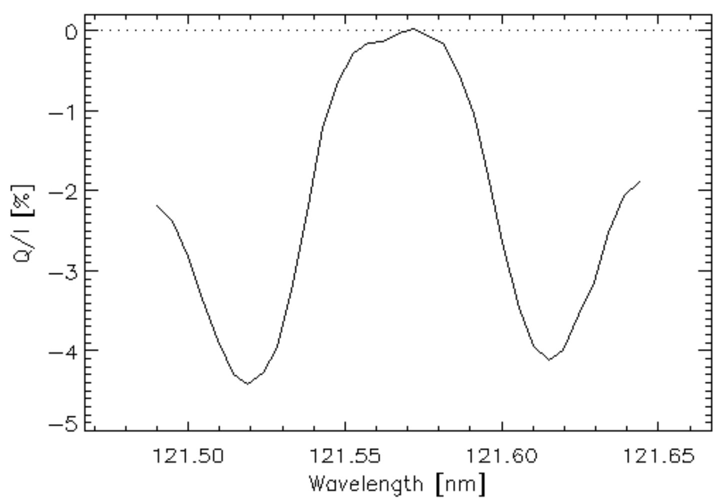


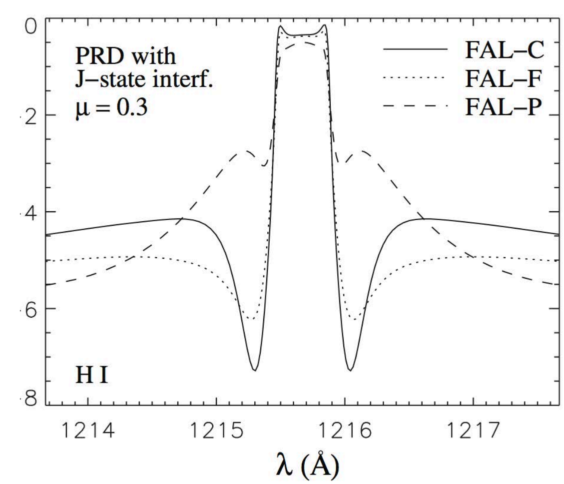
CLASP Initial Results



Further calibrations/investigations are required, but …

- **A few %** of polarization in the wing, and **a few of 0.1 %** in the core.
- A clear **C-to-L variation** in the wing of Q/I.
- Small-scale structures along the slit.
- Q/I profile is essentially **consistent with the model prediction**.





Belluzzi et al. 2012

CLASP Science Requirements

Table 1 Summary of technical requirements for CLASP.

Spectral window	$> \pm 0.05$ nm from Lyman-α center
Spectral resolution	0.01 nm
Spatial resolution	10 arcsec
Polarization sensitivity (line core)	0.1 % (121.57 ± 0.02 nm)
Polarization sensitivity (line wing)	0.5 % ($> \pm 0.05$ nm)
Polarization amplitude error	10 %
Angle error of linear polarization	2°

This is a 3σ error, 1σ is 0.03%!

Ishikawa R. et al, Sol. Phys. 2014

CLASP Polarization Error Budget

Table 3 Error budget for spurious polarization in the Lyman-α line core with full 0.0048 nm/pixel spectral sampling and nine-pixel (10 arcsec) binning in spatial directions.

Error breakdown	Error (1σ)
Photon noise with nine-pixel summing$^{(1)}$	0.019 %
Readout noise of CCD cameras$^{(2)}$	0.007 %
Fluctuation of exposure durations$^{(3)}$	10^{-4} %†
Time variation of source intensity$^{(4)}$	$\lesssim$0.018 %†
Intensity variation caused by pointing jitter$^{(5)}$	$\lesssim$0.023 %†
Image shift from waveplate rotation$^{(6)}$	$\approx$0 %†
Off-axis incidence with 200 arcsec$^{(7)}$	$\approx 10^{-4}$ %
Nonuniformity of coating on primary mirror$^{(8)}$	10^{-3} %
Error in polarization calibration$^{(9)}$	0.017 %
Root-sum-square	$\lesssim$0.039 %

To meet this requirement, we had to have 30 million photons/ resolution element.

Ishikawa R. et al, Sol. Phys. 2014

CLASP Radiometry

Table 6 Estimated CLASP throughput at Lyman-α.

Component	Material and thickness	Channel1/Channel2
Primary mirror	Cold-mirror coating	54.8 %(1)
Secondary mirror	Al + MgF_2 coating	82.0 %(1)
Half-waveplate	MgF_2, thickness of 1 mm	75.0 %(2)
Grating	Al + MgF_2 coating	29.0 %(3)
Camera mirror	Al + MgF_2 coating	82.0 %(1)
Polarization analyzer	Multilayer coating	54.5 %(4)
Back-illuminated CCD	Lumogen-E coating	30 %(5)
Molecular contamination	–	50 %
Throughput	–	0.66 %

Geometric area telescope is 437.8 cm^2. Effective area ~ 2.9 cm^2.

Ishikawa R. et al, Sol. Phys. 2014

CLASP Flux

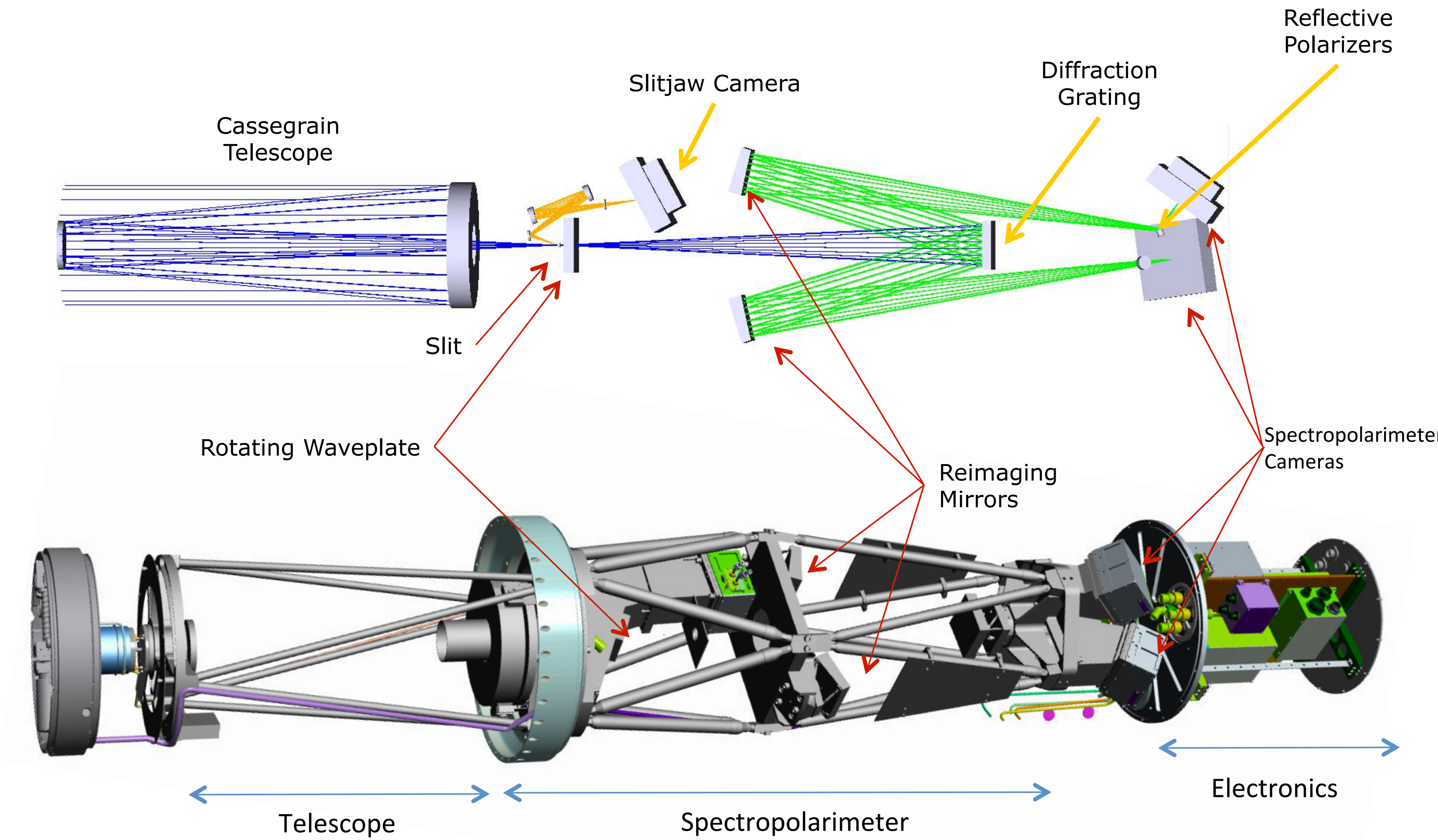
Table 2: HRTS Spectral Intensity Folded Through CLASP Instrument

	HRTS	HRTS	CLASP	CLASP
	Peak Intensity (ergs s^{-1} cm^{-2} sr^{-1} $Å^{-1}$)	Core Intensity (ergs s^{-1} cm^{-2} sr^{-1} $Å^{-1}$)	Peak Intensity (ph s^{-1} pix^{-1})	Core Intensity (ph s^{-1} pix^{-1})
Active Region	4.5e+05	1.6e+05	1.0e+05	3.7e+04
Quiet Region	1.9e+05	8.1e+04	4.3e+04	1.9e+04

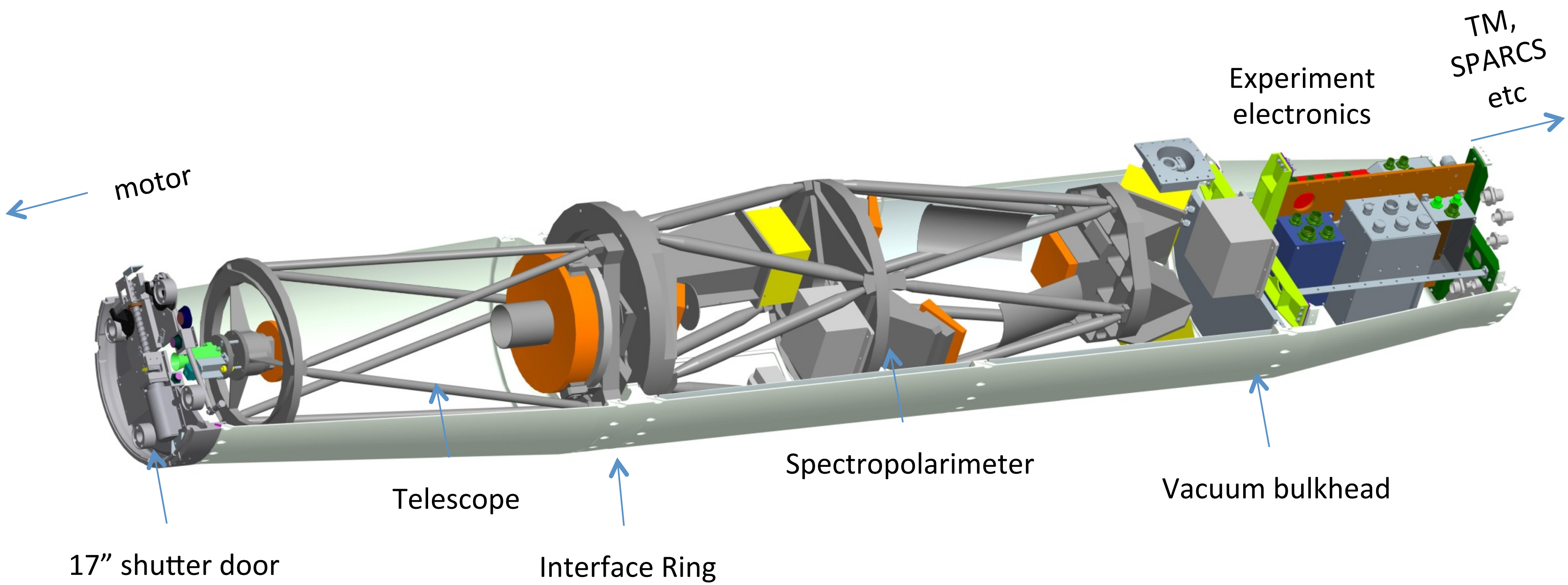
To get 30e6 photons, we have to sum 300 s and 5 pixels along the slit based on HRTS Lyman Alpha intensity.

Based on SUMER Lyman Alpha intensity, we have to sum roughly 300 s and 10 pixels along the slit.

CLASP Instrument

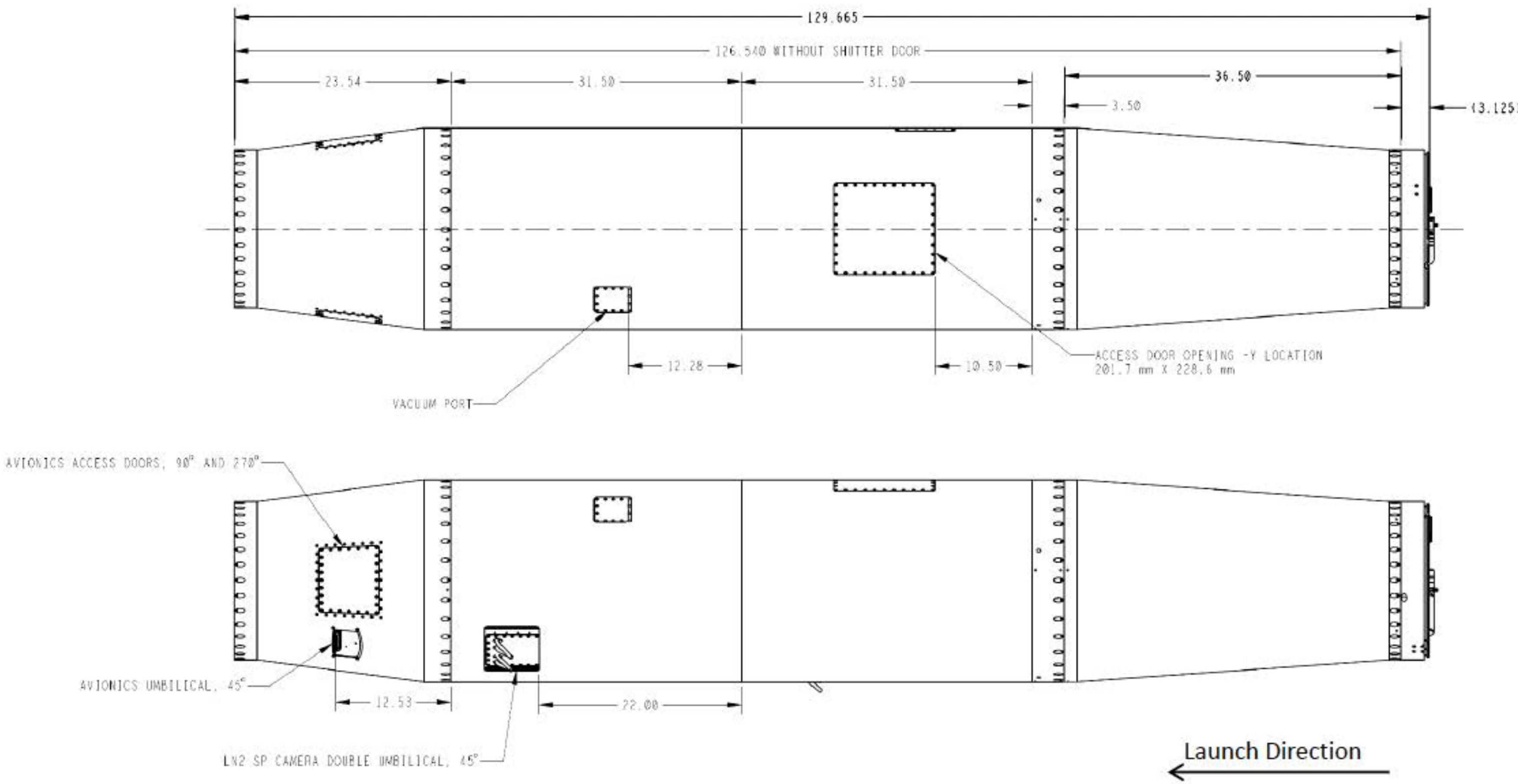


CLASP Experiment



- Telescope & Spectropolarimeter:
  - This section will be under vacuum at launch to allow cryogenic cooling of the camera cold blocks.
  - Interface Ring serves as single mounting point between skins and telescope+spectropolarimeter
  - Telescope structure is a truss cantilevered from the Interface Ring, made of hollow Invar rods.
  - Spectropolarimeter structure consists of two trusses, cantilevered from the Interface Ring. Baseline design is Invar.
- Electronics:
  - Non-vacuum section. Electronics boxes mounted on central plate (Hi-C heritage design).

CLASP Outline



CLASP Length & Diameter

	Length
Shutter Door	3.125
Telescope	36.50 in
Interface Ring	3.5 in
Spectrograph section	63.00 in.
Avionics Section	23.54 in
Total Length	129.665 in

	Diameter
Shutter door and Avionics interface	17 in
Interface Ring – Vacuum Bulkhead	22 in

CLASP Mass

	Weight	Mass
Telescope/Spectrograph structure	276-364 lbs	125 – 165 kg
Telescope/Spectrograph skin	182.5 lb	82.8 kg
Avionics Section (Including skin)	80.4 lb	36.5 kg
Total (Estimated)	538-626 lbs	244 – 284 kg
Total (Actual)	570.0 lbs	258.6 kg

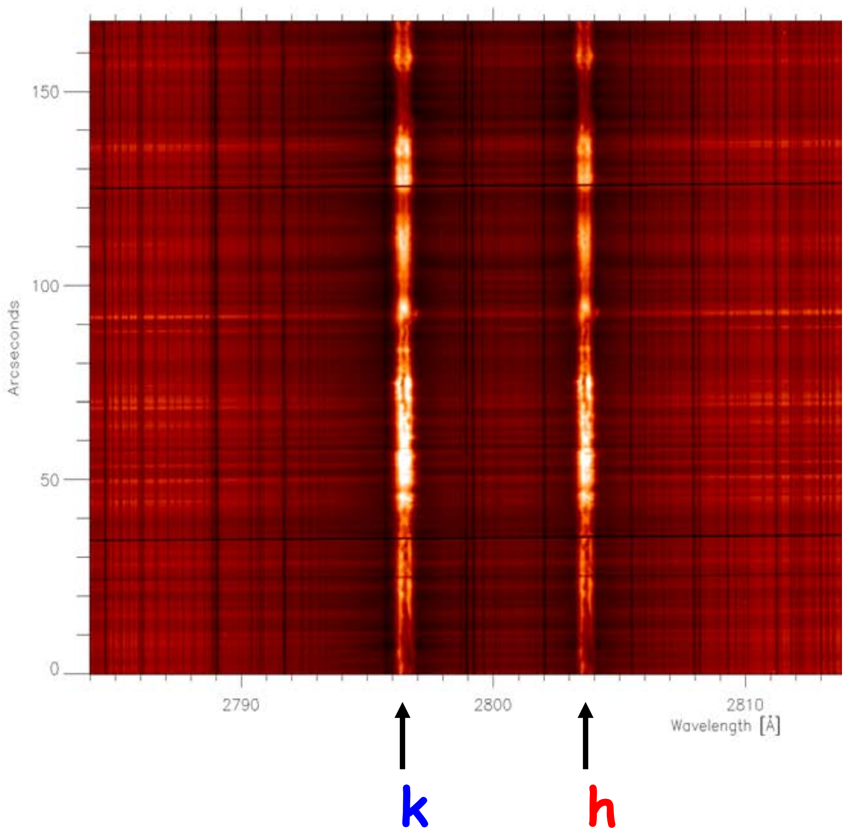
CLASP Power

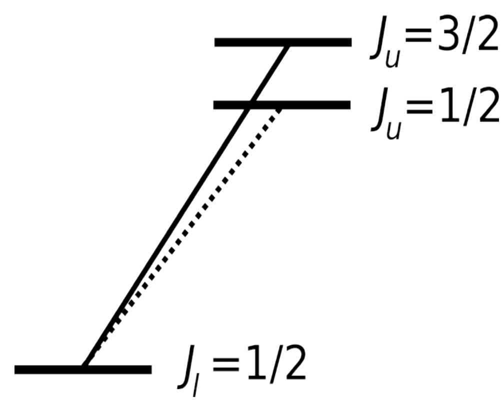
	Voltage	Load
Experiment A (cameras and DACS)	+28.8 V	5.72 A
Experiment B (PMU)	+28.8 V	0.70 A

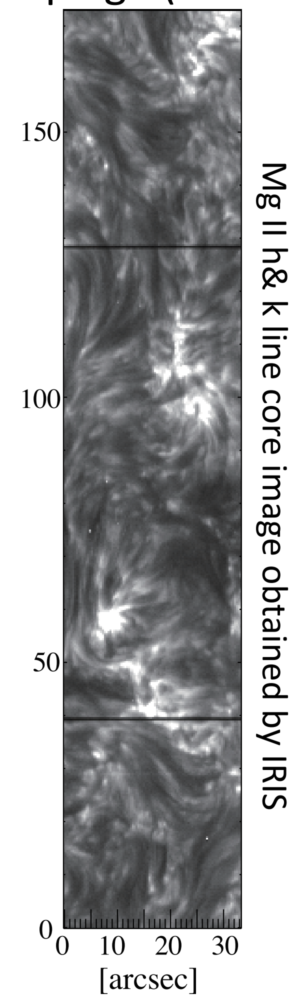
2 What is next for CLASP?

CLASP 2 proposes to change the wavelength to Mg II h&k, another set of magnetically sensitive spectral lines in the UV at ~ 280 nm.

Observing target: QS and plage (if available)



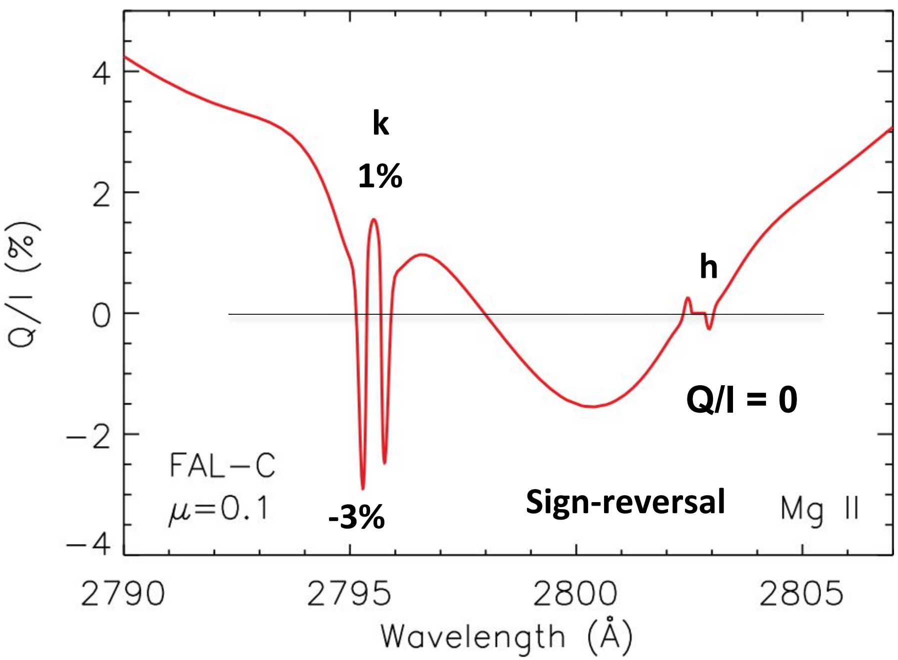


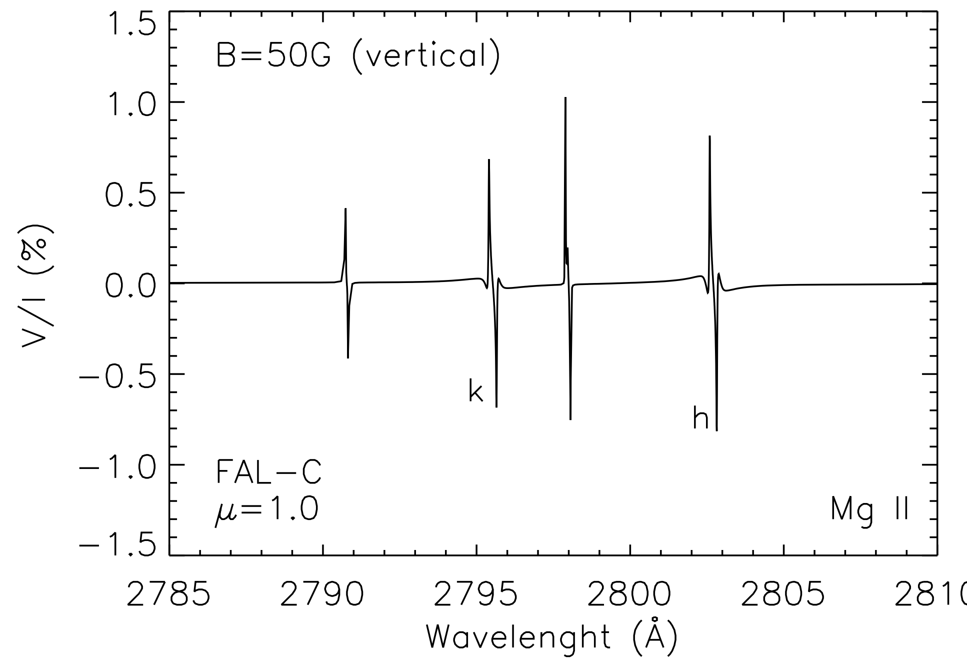


What is next for CLASP?

Linear polarization sensitive to scattering polarization and Hanle effect from 5-50 G.

Circular polarization sensitive to Zeeman effect for B > 50 G.





Proposed to fly in Spring 2018.

Belluzzi & Trujillo Bueno (2012; ApJ Letters)

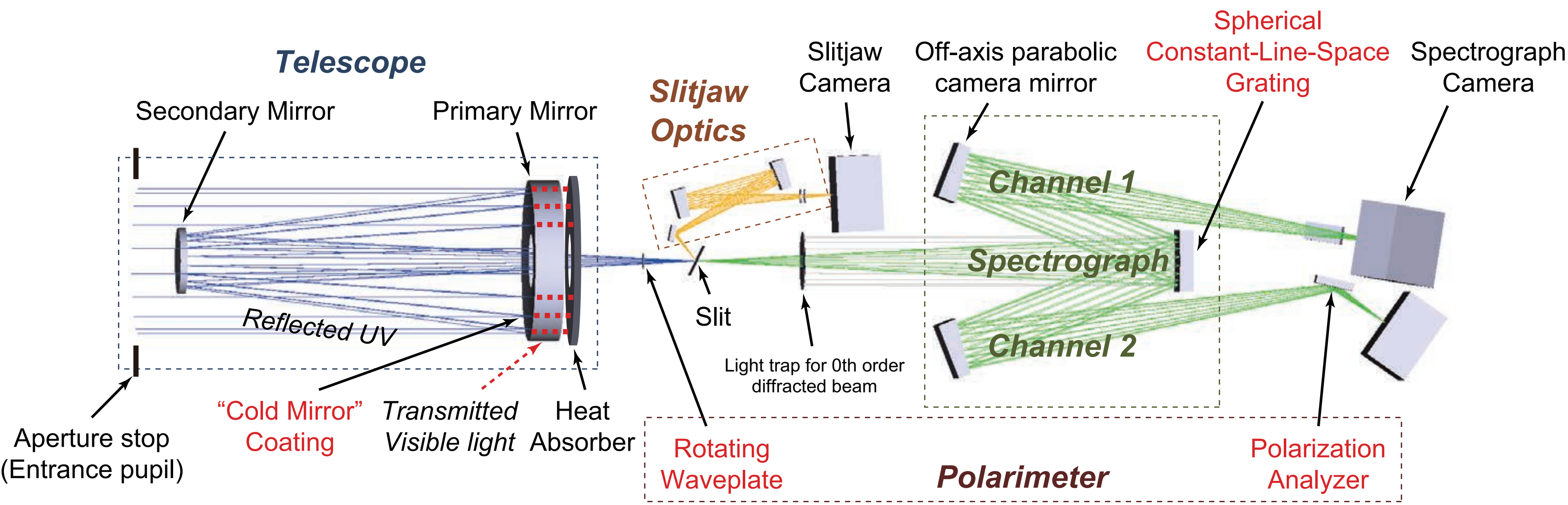
CLASP 2 Science Requirements

Table 1: Summary of Scientific Requirements

Observable	Requirement	
Target	On-disk, away from disk center (Quiet Sun and other structures)	
Polarization Sensitivity	0.1% (line core of Mg II h and k)	
Spectroscopic Resolution	0.025 nm	0.01 nm
Spectral Window	279.4 – 280.4 nm	121.1 – 122.1 nm
Spatial Resolution	$< 3''$	< 10 "
Temporal Resolution	< 5 minutes	

Red indicates CLASP 1 requirement

CLASP 2 Instrument



Red text indicates changes to CLASP instrument for CLASP 2.

CLASP 2 Effective Area and Flux

Based on estimates of coatings, we expect the EA to be ~ 12 cm^2 at 280 nm (roughly 4 times larger than CLASP 1 at 121 nm).

Line core in intensity in Mg II = 2e6 ergs/cm^2/s/sr/nm (in quiet region, Kohl & Parkinson 1976)

Expected flux in CLASP 2 ~ 1e6 ph/pix/s
[Note plate scale in 0.011 nm, 1.1”]

To achieve 30e6 photons, we must sum 30 s or 30 pixels or some combination.

CLASP 2 Mass/Volume/Power

The mass, volume and power of CLASP 2 is expected to be identical to CLASP 1.

CLASP 2 to PRIMROSE

Table 1: Summary of Scientific Requirements

Observable	Requirement	
Target	On-disk, away from disk center (Quiet Sun and other structures)	
Polarization Sensitivity	0.1% (line core of Mg II h and k)	
Spectroscopic Resolution	0.025 nm	0.01 nm
Spectral Window	279.4 – 280.4 nm	
Spatial Resolution	$< 3''$	1 “
Temporal Resolution	< 5 minutes	0.3 s

Red indicates PRIMROSE requirement

PRIMROSE Effective Area Requirement

Photons = I * EA * exptime * srperpix * nmperpix
EA = Photons/(I * exptime * srperpix * nmperpix)
EA = 30e6 / (2e6 ergs/cm^2/s/sr/nm * 0.3 s * 2.4e-11 sr/pix * 0.01 nm/pix)

EA = 1500 cm^2 (2 orders of magnitude larger than CLASP 2)